PCB Aroclor Concentrations in Puget Sound Sediments

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[Editor's note: Tables and Figures for Dutch *et al.* appear at the end of this paper.]

Abstract
Concentrations of 8 PCB Aroclors were determined for 300 sediment samples collected throughout Puget Sound during 1997-1999 as part of a joint monitoring project conducted by the Washington State Department of Ecology and the National Oceanic and Atmospheric Administration. The highest total PCB Aroclor concentrations (as Aroclor mixtures) were measured in samples collected from the Whidbey Basin and Central Puget Sound regions, especially those from the urban/industrialized embayments of Everett Harbor, Elliott Bay, Commencement Bay, and around Bainbridge Island, with concentrations diminishing from the head to the mouth of these embayments. Washington State Sediment Management Standards for total PCB Aroclor concentrations were exceeded at 21 of the 300 stations, again, in sediment from some of the most urban/industrialized embayments of Puget Sound (Port of Everett, Elliott Bay, lower Duwamish River, Thea Foss and Hylebos Waterways, and Sinclair Inlet). Lowest PCB concentrations were recorded in samples from the Strait of Georgia, Admiralty Inlet, Hood Canal, and southern Puget Sound.

Introduction
The Washington State Department of Ecology (Ecology) and the National Oceanic and Atmospheric Administration (NOAA) conducted a joint monitoring program from 1997 through 1999 to quantify the magnitude and extent of toxicity, chemical contamination, and impacted benthos in the sediments of Puget Sound (Long *et al*. 1999, 2000, 2002). This joint effort combined the Puget Sound Ambient Monitoring Program's (PSAMP) Sediment Component administered by Ecology and the National Status and Trends (NS&T) Program conducted by NOAA. Data from this survey were evaluated to identify geographic patterns in sediment quality, the spatial extent of degraded conditions, and the relationships among individual measures. Sediments from 300 stations, chosen with a random, stratified sampling design, were collected from Puget Sound basins and channels extending from the U.S./Canada border to the southern-most bays and inlets near Olympia and Shelton, including portions of Admiralty Inlet and Hood Canal. As part of this study, samples were analyzed to determine concentrations of polychlorinated biphenyls (PCBs), including 8 PCB Aroclors and 19 PCB congeners. Results of the PCB Aroclor analyses are summarized in this paper to illustrate the levels and spatial patterns of PCB Aroclor contamination throughout Puget Sound.

Methods
Sediment samples were collected from the research vessel *Kittiwake* with a double 0.1 m^2, stainless steel, vanVeen grab sampler. A composite sediment sample was collected from each station, consisting of a homogenate of the top 2-3 cm of sediment from 3 to 6 grab samples. Samples were sent to Ecology's Manchester Environmental Laboratory (MEL) for PCB analysis. Sample extraction and analytical methods followed the protocols used by both Ecology (PSEP 1997) and NOAA (Lauenstein and Cantillo 1993). Specifically, analyses of chlorinated pesticides and PCBs followed U.S. EPA Method 8081/8082, using gas chromatography (GC) methods with dual dissimilar column confirmation and electron capture detectors. Concentrations were determined for Aroclors 1016, 1221, 1232, 1242, 1248, 1254, 1260, and 1268. Reporting limits for PCB Aroclors ranged from 0.28 to 320 ppb dry wt.

For this paper, PCB Aroclor data generated for each of the 300 stations are summarized and compared among stations and regions in Puget Sound to look for general trends, spatial patterns and gradients in concentrations, and comparison with Washington State Sediment Management Standards (Ecology 1995). The concentrations of seven of the Aroclors (1268 excluded) were also summed to estimate "total PCB Aroclor concentrations" (as ppb, dry wt.). In these summations, undetected values were treated as zeros; only the detected concentrations were included. Total Aroclor concentrations were compared among six sampling regions and among individual stations, and were compared to the Washington State Sediment Quality Standard (SQS) value of 12 mg/kg_{oc} and a Cleanup Screening Level (CSL) of 65 mg/kg_{oc}. Sediment sampling sites typically are classified as not contaminated when chemical concentrations are equal to or lower than the SQS values. In contrast, management actions and/or additional testing typically are required when chemical concentrations exceed the CSL values.

Results

Station and Regional Data Summaries
Summary statistics of the concentration of each of the Aroclors measured for all 300 stations are displayed in Table 1. Aroclors 1254 and 1260 were detected most frequently (in 100 and 87 samples, respectively) among the 300 samples tested. The mean, median, and maximum concentrations of Aroclors 1254 and 1260 were the highest among the 8 Aroclors. Aroclors 1242, 1248, and 1268 were detected in 10, 10, and 4 samples, respectively; whereas none of the samples had detectable concentrations of Aroclors 1016, 1221, and 1232. The summed concentrations (including undetected concentrations) of total PCB Aroclors ranged from 18.7 to 4420 ppb, a difference of over 200x between the highest and lowest concentrations. By summing the concentrations of seven Aroclor mixtures, the concentrations of some of the same congeners would be accounted for multiple times. Therefore, the "total" concentrations derived by these calculations probably are higher than a true total.

Summary statistics for the total PCB Aroclor values (ppb, dry wt.) for each station were generated for each of 6 sediment-monitoring regions and for the total study area (Table 2). Mean and maximum concentrations of total Aroclors were highest in the Whidbey Basin region, which included Everett Harbor, and in the central Puget Sound region, which included Elliott Bay, Commencement Bay, and Sinclair Inlet. PCB concentrations were considerably lower in the Strait of Georgia, Admiralty Inlet, Hood Canal, and southern Puget Sound samples. All individual Aroclors were undetected in large majorities of the samples from the latter five regions. The concentrations of total Aroclors (expressed as ppm_{oc}) exceeded the state SQS value of 12 ppm_{oc} in 20 samples from the central Puget Sound region. One sample from the Whidbey Basin had a total Aroclor concentration greater than the SQS. The 21 samples in which total Aroclor concentrations exceeded the state standard represented an area of about 7.2 km^2, equivalent to 0.3% of the total survey area of 2363 km^2. None of the other 279 samples tested in this survey had PCB concentrations that exceeded the state standard.

Spatial Patterns and Gradients in PCB Aroclor Concentrations.
The distribution of concentrations of total PCB Aroclors (as ppb dry wt.) calculated for all 300 stations were grouped into four percentiles and mapped to identify spatial patterns and gradients in distribution throughout Puget Sound (Figures 1-5). Fifty percent of the total PCB Aroclor concentrations were at or below practical quantitation limits set by laboratory instrumentation. Another 25% of the concentrations ranged from 2.5-17.3 ppb, 19% of the concentrations ranged from 18.0-163.0 ppb, and 6% ranged from 197 to 3400 ppb. Concentrations generally were highest in the urban/industrialized embayments of Everett Harbor, Elliott Bay, Commencement Bay, Sinclair Inlet and around Bainbridge Island, and tended to diminish from the head to the mouth of these embayments (Figures 2-5). Lowest concentrations generally occurred in samples collected in the southern Strait of Georgia, northern Puget Sound, Possession Sound, Admiralty Inlet, Hood Canal, and the basins and inlets of southern Puget Sound.

Comparison of Total PCB Aroclor Concentrations with Sediment Standards
Concentrations of total PCB Aroclors for each station were compared with Washington State Sediment Management Standards derived with matching sediment chemical and biological effects data (Ecology 1995) (Figures 6-9). Most samples from the central basin of Puget Sound, Rich Passage, and most of the basins and bays near Bainbridge Island had relatively low PCB concentrations, less than the SQS value of 12 ppm_{oc} (Figure 6). There were a few samples collected near Bainbridge Island and in Sinclair Inlet with PCB concentrations somewhat higher than the others and the concentration in one sample from Sinclair Inlet exceeded the SQS value. PCB concentrations in most samples from Commencement Bay were less than the SQS, but the concentrations in three samples from the Hylebos and Thea Foss waterways were much higher, exceeding the SQS values (Figure 7). One sample from innermost Everett Harbor had a total Aroclor concentration of 34 ppm_{oc}, approximately triple the SQS value (Figure 8). The highest concentrations of total Aroclors were recorded in samples from Elliott Bay and the adjoining lower Duwamish River waterways (Figure 9). PCB concentrations were elevated relative to the SQS in samples collected along the Seattle waterfront, in the west and east waterways of the Duwamish River, and the middle reaches of the bay. The total Aroclor concentration of 122 ppm_{oc} in a sample from the east waterway exceeded both the SQS and CSL values. Concentrations generally diminished seaward into the outer reaches of the bay.

Summary
Concentrations of 8 PCB Aroclors were determined for 300 sediment samples collected throughout Puget Sound during 1997-1999 as part of a joint monitoring project conducted by the Washington State Department of Ecology and the National Oceanic and Atmospheric Administration. Aroclors 1254 and 1260 were detected in 100 and 87

of the 300 samples, respectively. Aroclors 1242, 1248, and 1268 were detected in 10, 10, and 4 of the 300 samples, respectively; while 3 others (1016, 1221, and 1232) were not measured above practical quantitation limits. The highest total PCB concentrations (as Aroclor mixtures) were measured in samples collected from the Whidbey Basin and Central Puget Sound regions, especially those from the urban/industrialized embayments of Everett Harbor, Elliott Bay, Commencement Bay, and around Bainbridge Island. These high concentrations tended to diminish from the head to the mouth of these embayments. PCB Aroclor concentrations at 21 of 300 stations exceeded the Washington State Sediment Management Standard (SMS) value of 12 ppm (organic carbon normalized). These 21 samples were collected in the Port of Everett, Elliott Bay, lower Duwamish River, Thea Foss and Hylebos Waterways, and Sinclair Inlet. One sample from the East Duwamish River waterway exceeded the Cleanup Screening Level of 65 ppm (organic carbon normalized). Lowest PCB concentrations were recorded in samples from the Strait of Georgia, Admiralty Inlet, Hood Canal, and southern Puget Sound.

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Table 1. PCB Aroclor concentration summary (ppb, dry wt.) for the 1997-1999 PSAMP/NOAA Sediment Monitoring Survey (undetected concentrations included).

Chemical	Mean (ppb)	Median (ppb)	Minimum (ppb)	Maximum (ppb)	Range (ppb)	N	No. of Undetected Values	No. of Detected Values	% Undetected
PCB Aroclor 1016	8.2	6.1	0.6	170.0	169.4	300	300	0	100.00
PCB Aroclor 1221	10.6	6.9	2.5	170.0	167.5	300	300	0	100.00
PCB Aroclor 1232	9.1	6.8	2.5	170.0	167.5	300	300	0	100.00
PCB Aroclor 1242	8.8	6.3	2.1	170.0	167.9	300	290	10	96.67
PCB Aroclor 1248	10.6	6.3	1.2	320.0	318.8	300	290	10	96.67
PCB Aroclor 1254	21.5	7.6	2.1	560.0	557.9	300	200	100	66.67
PCB Aroclor 1260	41.9	7.6	1.2	3400.0	3398.8	300	213	87	71.00
PCB Aroclor 1268	10.5	5.5	0.5	52.0	51.5	117	113	4	96.58
Total Aroclors	110.8	53.0	18.7	4420.0	4401.3	300	NA	NA	NA

Table 2. Regional summary of total detected PCB Aroclors (ppb, dry wt.) in Puget Sound sediments from the 1997-1999 PSAMP/NOAA Sediment Monitoring Survey.

Region	Mean (ppb)	Median (ppb)	Minimum (ppb)	Maximum (ppb)	Range (ppb)	N	No. of samples/region with all individual aroclors undetected	No. of regional samples exceeding WA State Sediment Quality Standards (SQS) (12 ppm oc) and regional spatial extent (km2) of PCB Aroclor contamination
Strait of Georgia	0.19	0.00	0.00	8.10	8.10	61	59	0 (0.0)
Whidbey Basin	100.80	0.00	0.00	3400.00	3400.00	39	21	1 (0.1)
Admiralty Inlet	2.89	0.00	0.00	26.00	26.00	9	8	0 (0.0)
Central Puget Sound	92.46	14.20	0.00	2007.90	2007.90	128	47	20 (7.1)
Hood Canal	0.35	0.00	0.00	7.30	7.30	21	20	0 (0.0)
South Puget Sound	4.62	0.00	0.00	59.00	59.00	42	30	0 (0.0)
Total Study Area	**53.35**	**0.00**	**0.00**	**3400.00**	**3400.00**	**300**	**185**	**21 (7.2)**

Figures

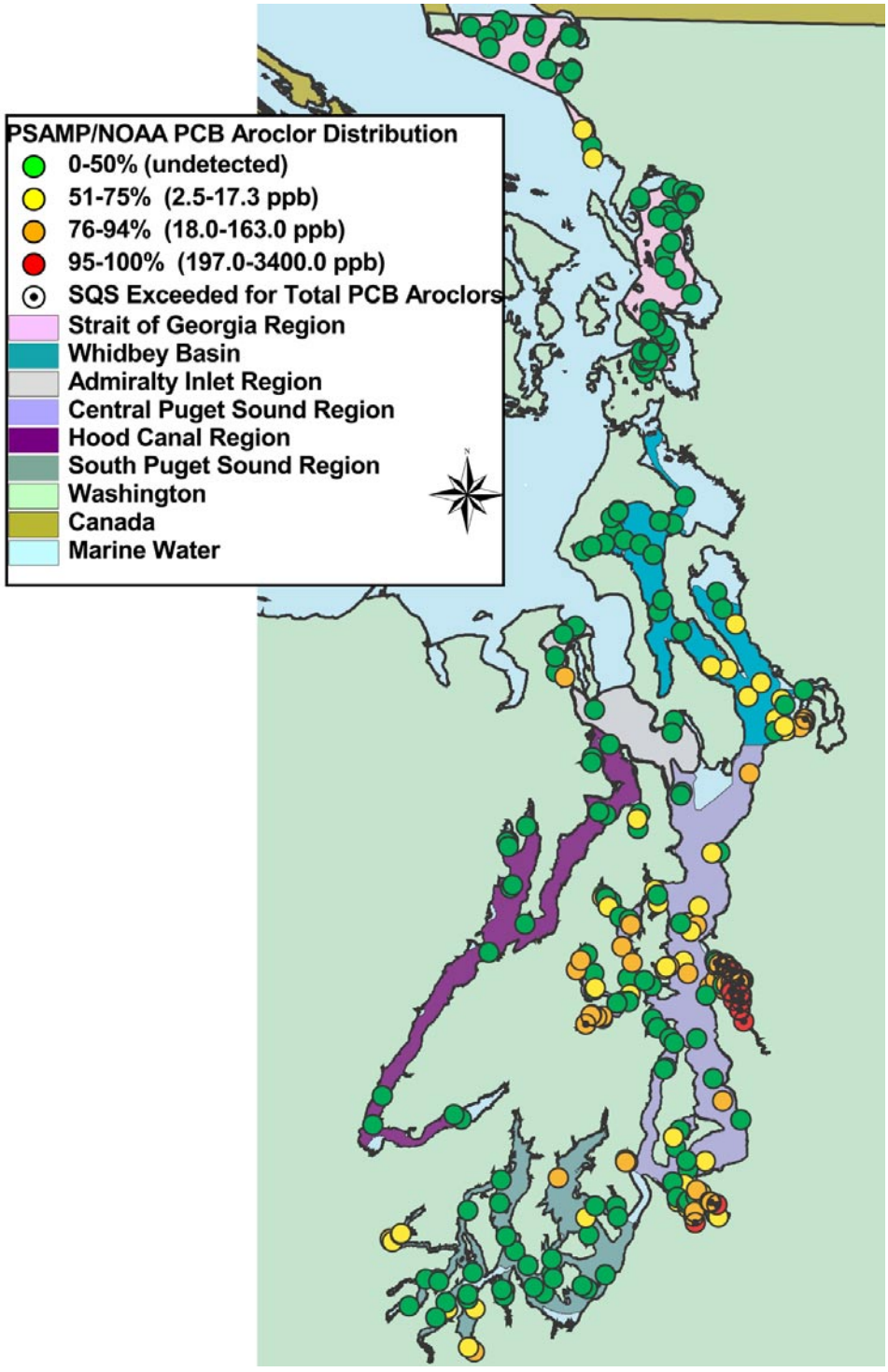

Figure 1. Distribution of total PCB Aroclor concentrations (ppb, dry wt.) in sediments from the 1997-99 PSAMP/NOAA sediment survey, and comparison with Washington State Sediment Quality Standards (SQS) (Ecology, 1995).

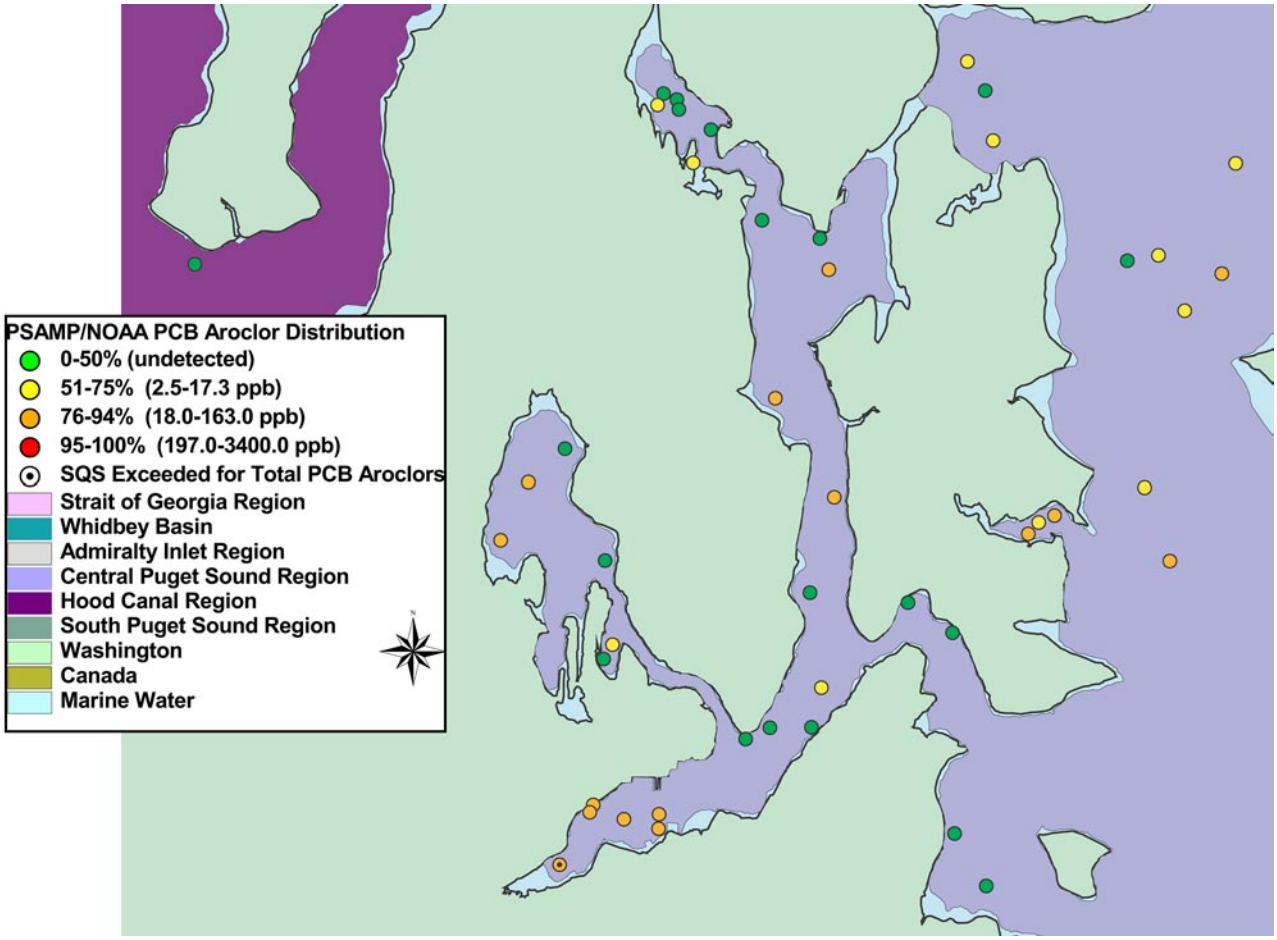

Figure 2. Distribution of total PCB Aroclor concentrations (ppb, dry wt.) in sediments from the 1997-99 PSAMP/NOAA sediment survey—Bainbridge Basin area, and comparison with Washington State Sediment Quality Standards (SQS) (Ecology, 1995).

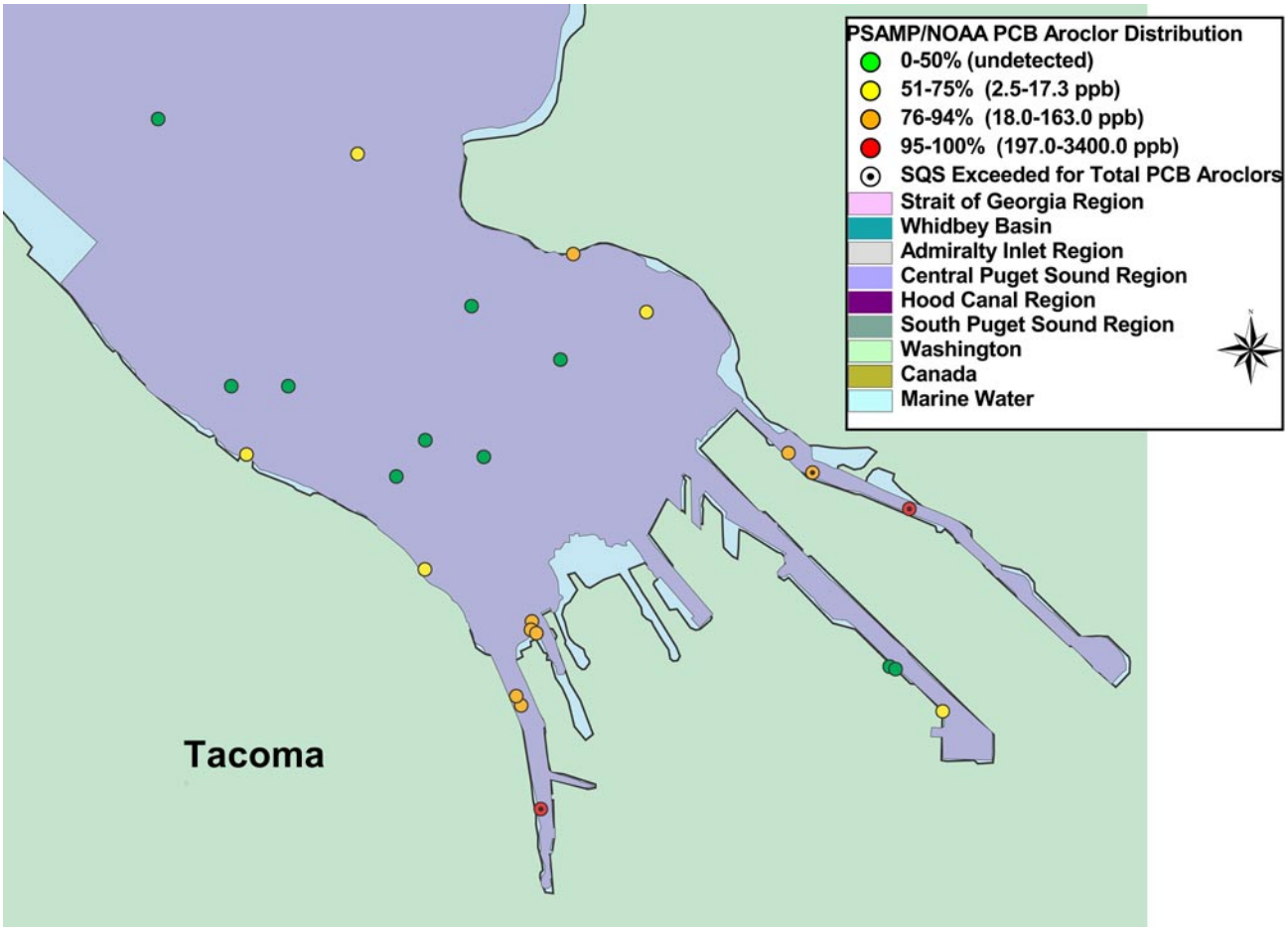

Figure 3. Distribution of total PCB Aroclor concentrations (ppb, dry wt.) in sediments from the 1997-99 PSAMP/NOAA sediment survey—Commencement Bay area, and comparison with Washington State Sediment Quality Standards (SQS) (Ecology, 1995).

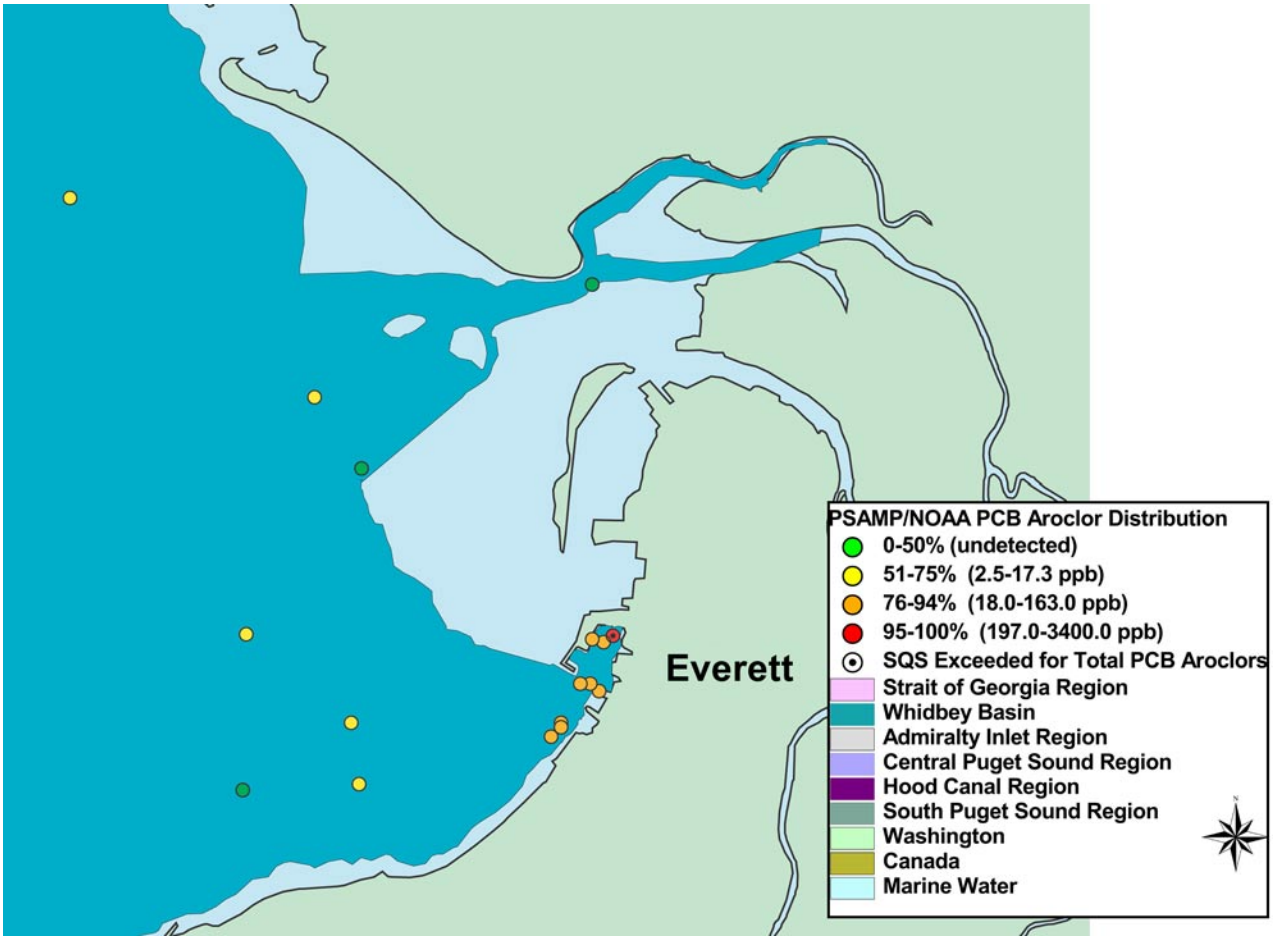

Figure 4. Distribution of total PCB Aroclor concentrations (ppb, dry wt.) in sediments from the 1997-99 PSAMP/NOAA sediment survey—Everett Harbor area, and comparison with Washington State Sediment Quality Standards (SQS) (Ecology, 1995).

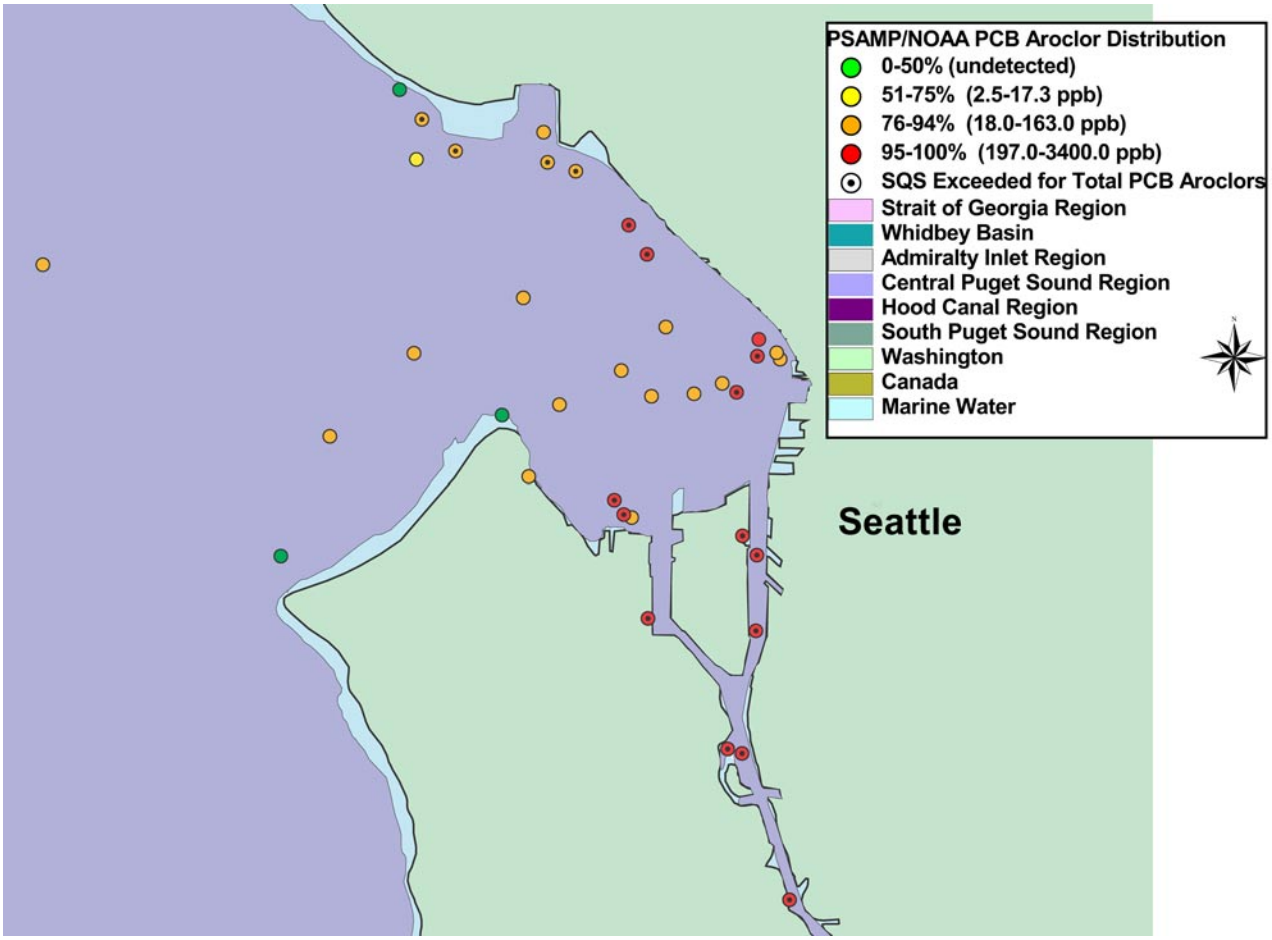

Figure 5. Distribution of total PCB Aroclor concentrations (ppb, dry wt.) in sediments from the 1997-99 PSAMP/NOAA sediment survey—Elliott Bay area, and comparison with Washington State Sediment Quality Standards (SQS) (Ecology, 1995).

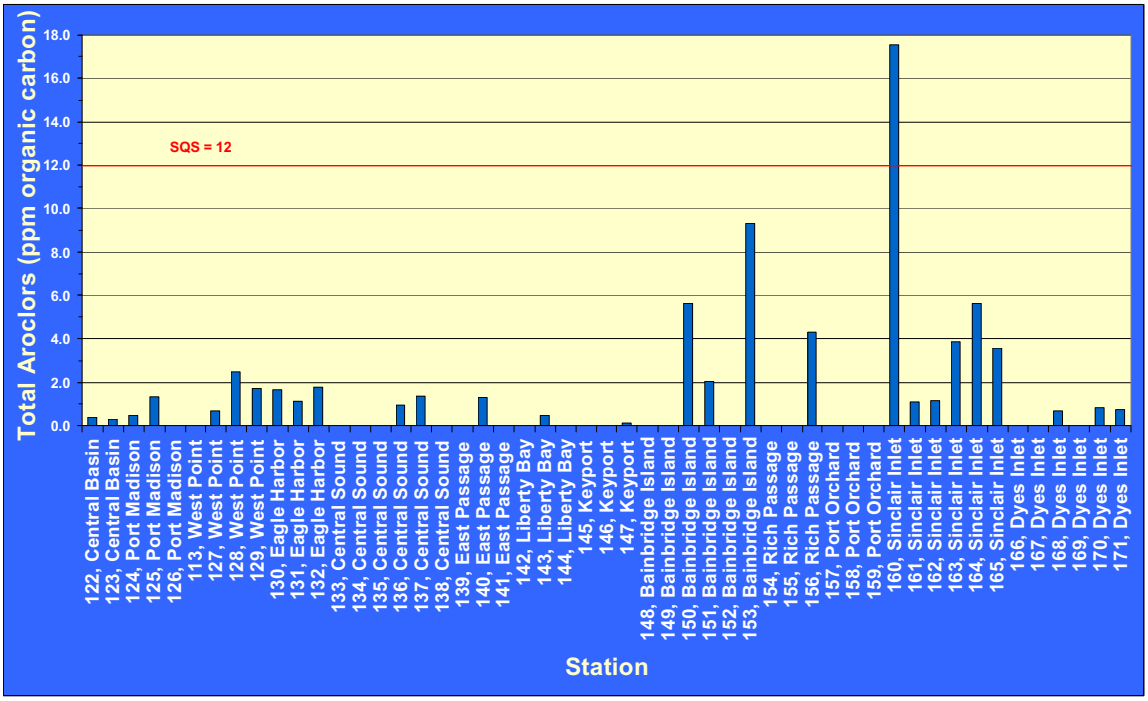

Figure 6. Total PCB Aroclor concentrations (ppm, organic carbon) for the Bainbridge Basin sampled in the 1997-99 PSAMP/NOAA sediment quality survey.

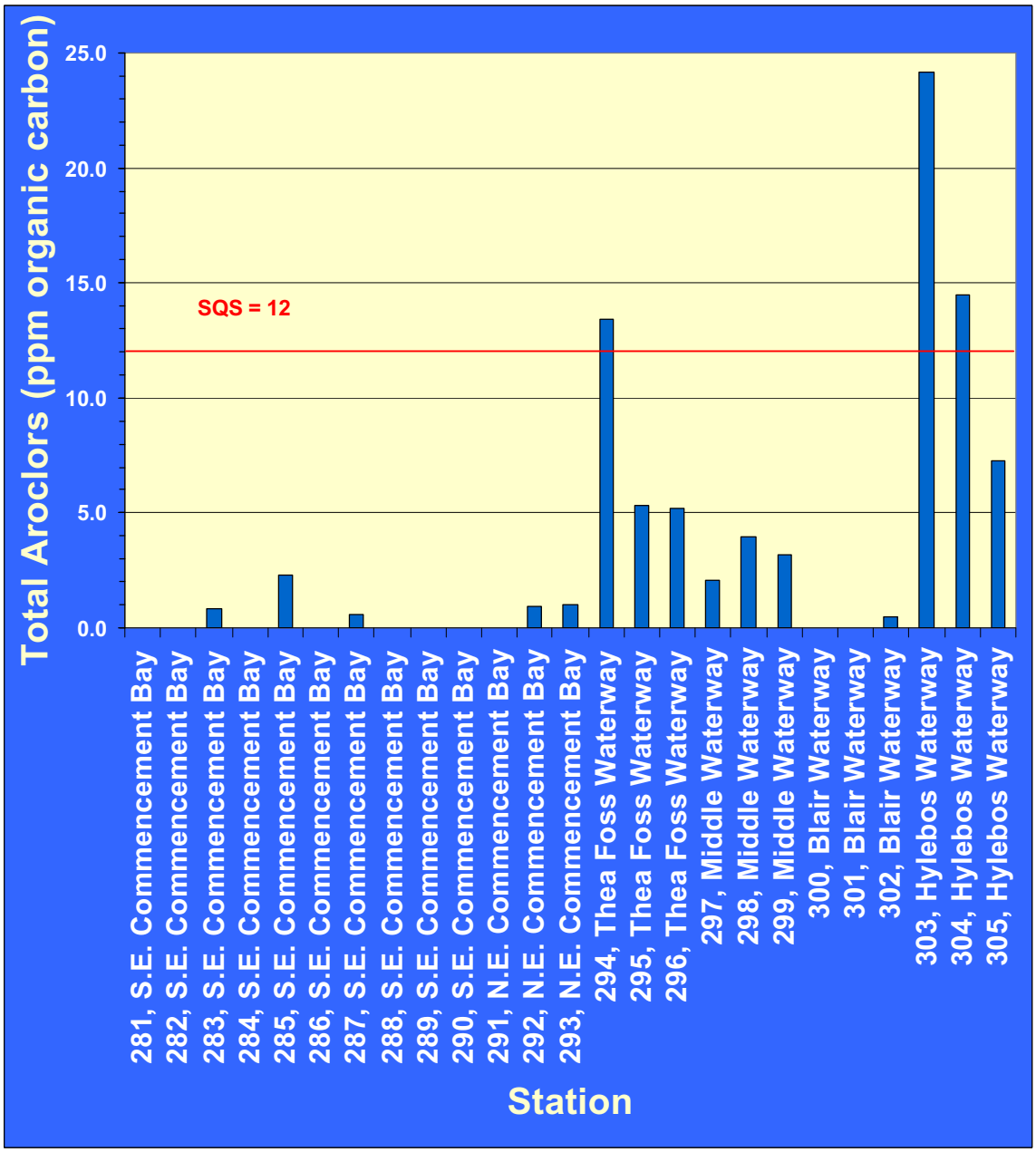

Figure 7. Total PCB Aroclor concentrations (ppm, organic carbon) for Commencement Bay sampled in the 1997-99 PSAMP/NOAA sediment quality survey.

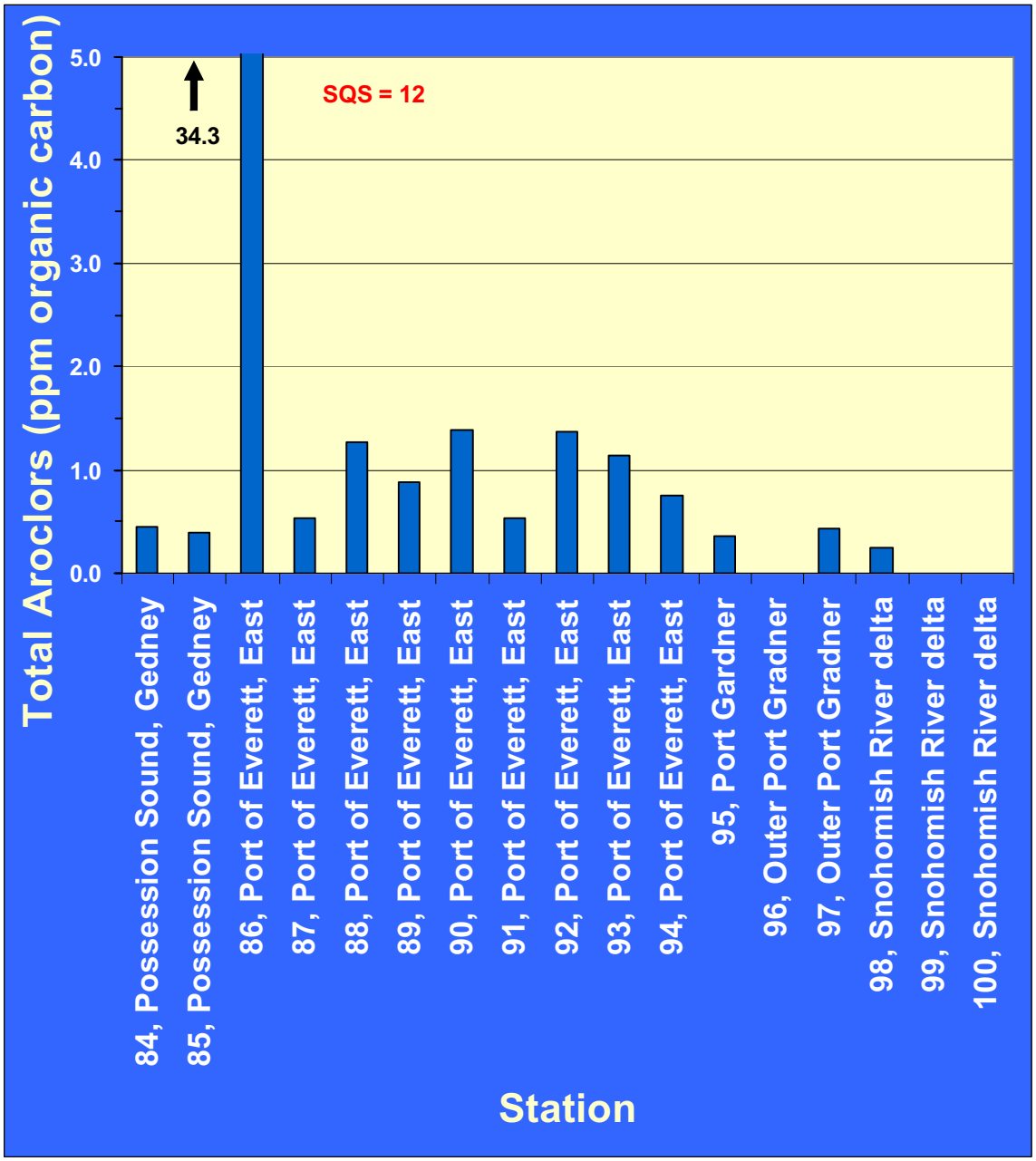

Figure 8. Total PCB Aroclor concentrations (ppm, organic carbon) for Everett Harbor sampled in the 1997-99 PSAMP/ NOAA sediment quality survey.

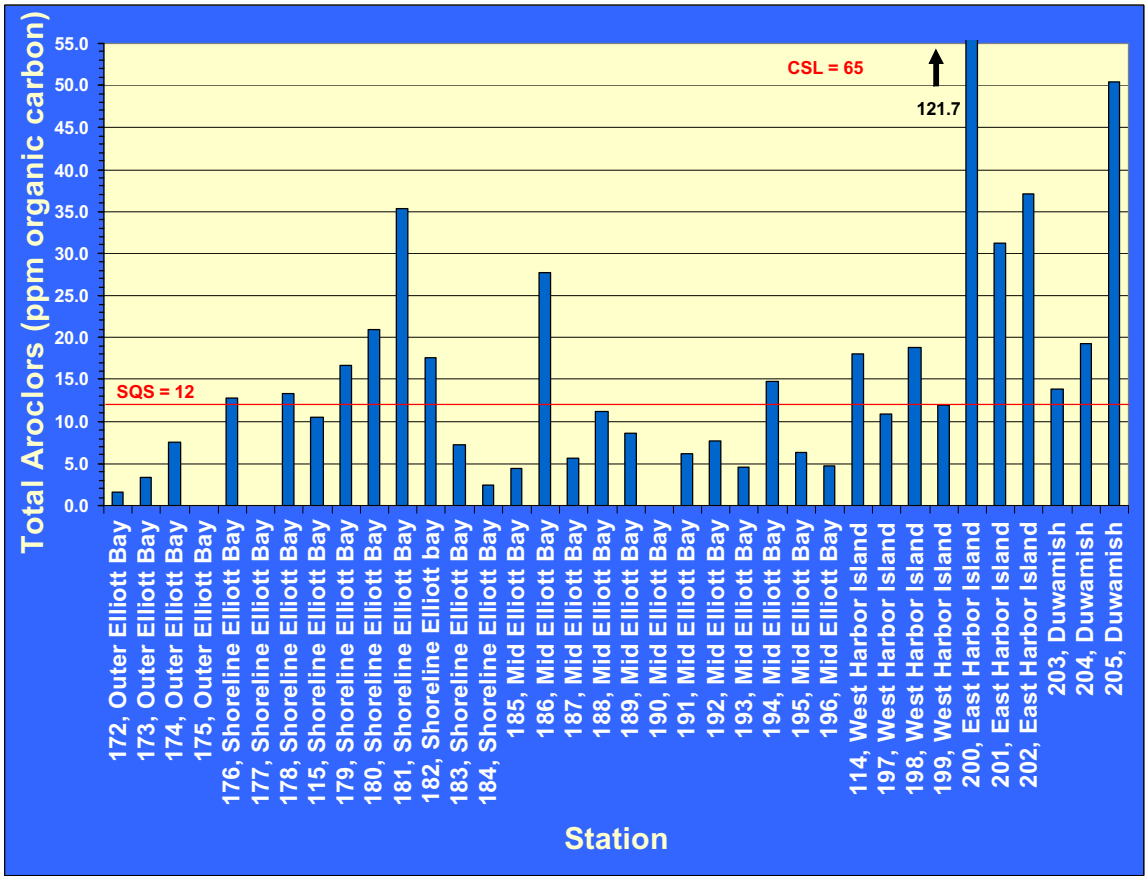

Figure 9. Total PCB Aroclor concentrations (ppm, organic carbon) for Elliott Bay sampled in the 1997-99 PSAMP/ NOAA sediment quality survey.